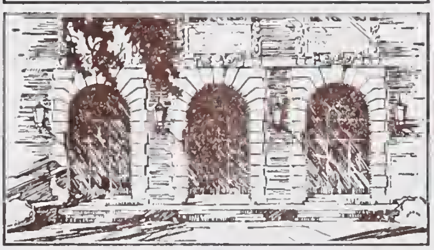

UIUCDCS-R-75-757

PERFORMANCE EVALUATION OF THE DIGITAL AM RECEIVER

by

P. L. Mohan
E. Bracha
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April 1975

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN · URBANA, ILLINOIS

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ABSTRACT

The performance of the first digital AM receiver to employ Burst techniques is discussed. Some relevant parameters are evaluated.

I. Introduction

In this memo, we discuss the performance of the digital AM receiver shown in Figure 1. The burst encoder generates a sample of the r.f. signal every τ seconds. These samples are fed into the digital lowpass filter which in turn generates n samples of the lowpass signal during any period of the carrier, T.* The sample with the maximum value among k samples is picked by the peak detector. Hence, the output signal of the peak detector, y(t), is equal to the value of this peak sample for approximately $\frac{k}{n}T$ second. When k is equal to n and the local clock is in synchronization with the input carrier, typical waveforms of r(t), x(t), y(t) and a(t) are shown in Figure 2. That the output signal of the peak detector is indeed a reasonable approximation of the desired audio signal when r.f. signals at other carrier frequencies are also present at the input of the receiver is demonstrated in Figure 3.†

We note that the receiver described here is basically a synchronous detector. The variation in local clock frequency with respect to the input carrier frequency is a possible source of distortion in the received signal. However, as will be shown in Section II, the distortion introduced by the local clock jitters can be made negligibly small by choosing the peak sample value from a large number of samples taken at time instants at which the carrier phases are different. Hence, a very stable local clock is not required in this receiver as in the case of synchronous detectors.

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*n is less than $\frac{T}{\tau}$

†The output signal of the peak detector depends only on the sample values of the r.f. signal at time instants when the carrier is at its positive peak. The train of sample pulses at these time instants is shown in Figure 3 as p(t).

In Section II, the frequency response of the digital filter is plotted for different sets of weights $c_1, c_2, \ldots, c_N$. These weights are chosen to be 1 in the receiver implemented to date. Both flatter response in the passband and larger attenuation in the stopband can be obtained by choosing different sets of weights, increasing number of delay stages, and using different filter configurations.

Since samples generated by the burst encoder and the peak detector are digital signals, quantization noise is another source of distortion in the receiver. We calculate the value of signal-to-quantization noise ratio, SNR_Q, in Section IV. This value of signal-to-noise ratio is not a fundamental limitation of the receiver performance since finer quantization can be achieved easily by using longer burst sum registers. We must also point out here that inadequacies of signal-to-noise ratio as a performance measure have been commonly recognized in voice coding literature. Finer assessments of the receiver require us to supplement the signal-to-noise figure with corrections for subjective and perceptual factors.

II. Noise Due to Jitters in Local Clock

For simplicity in our discussions here, we shall neglect the error due to quantization throughout this section. Again, quantization noise is evaluated separately in Section IV.

In a synchronous detector, any errors in the carrier frequencies at the transmitter and receiver give rise to distortions in the received signal. In the AM receiver shown in Figure 1, variations in local clock frequency also introduces similar distortions. The lowpass signal at the output of the receiver is attenuated whenever a sample chosen by the peak detector is one generated at times when the r.f. carrier is not at its peak.

The amount of attenuation may vary with time as the local clock frequency varies and thus causes noise in the audio frequency range.

To estimate the worst case level of the noise caused by sampling time error, let us suppose for the moment that the peak detector generates an output sample every carrier cycle. Moreover, its amplitude is equal to the value of the maximal sample among n samples at its input and n is an integer. That is, k is equal to n. The maximum error occurs when the samples are generated at time instants shown in Figure 4(a). The amount of error is given by

$$\varepsilon = 1 - \cos \frac{\pi}{k}$$

The associated signal-to-noise ratio, SNR_J, is plotted as a function of k in Figure 4 (b). Clearly, this signal-to-noise ratio can be made smaller by increasing the sampling rate and local clock frequency.

When n is not an integer, the phase angles of the carrier at sampling time instants are different for more than one period of the carrier. Let I(n) be the smallest integer such that $\frac{2\pi\, I(n)}{n}$ is an integer multiple of 2π. The value of SNR_J is equal to $1 - \cos\left(\frac{\pi}{I(n)}\right)$. When k is chosen to be equal to or larger than I(n). (In this case, the output of the peak detector is constant for a duration of $\frac{k}{n}T$.) In the current version of the receiver, 5.6 samples of the lowpass signal are generated at the output of the lowpass filter every T seconds. That is, n is equal to 5.6. Hence, I(n) is equal to 28. The value of k can be easily chosen to be larger than 28. With k currently being 6.4, the worst case SNR_J is equal to 15db as given by Figure 4 (b).

III. <u>Characteristics of the Lowpass Filter</u>

The lowpass filter in the receiver implemented todate consists of twenty delay sections with weights $c_1, c_2, \ldots, c_{20}$ all equal to 1. Its frequency response is as shown in Figure 5. For the purpose of demonstrating

the performance of the digital receiver, we found this configuration quite satisfactory.

For operation in more realistic environment in which other stations are closer by and additive random noise is also present at its input, the lowpass filter must have flatter response in its passband as well as better noise suppression characteristics. Both these improvements can be obtained by increasing the length of data window and modifying its shape. For example, it is relatively easy to choose the set of weights $c_1, c_2, \ldots, c_N$ so that the data window is triangular. The corresponding frequency response is shown in Figure 6. We note that for carrier f_0 at 100 kH_z, the filter bandwidth is sufficient for audio signal.

IV. Quantization Noise

The output signal of the peak detector is a PCM coded version of the audio signal. It can assume one of ten possible levels. The quantization step, Δ, is chosen to be

$$\frac{2\sqrt{2}\, V_{rms}}{10}$$

Where V_{rms} is equal to the maximum r.ms. amplitude of the audio signal. Hence, the signal-to-quantization noise SNR_Q of the system is equal to

$$SNR_Q = \frac{(V_{rms})^2}{\frac{\Delta^2}{12}}$$
$$= 26.5 \quad \text{db}$$

Clearly, the quantization noise figure can be improved by increasing the number of bits in the block sum registers and the peak detector. Since the operation of the burst encoder in the front-end of the receiver is closer to that in an adaptive delta modulation system than in a straightforward PCM system, we feel that the quantization noise can be decreased by

increasing the number of bits in the peak detector alone. Such modification will be incorporated in later versions of the receiver, together with analytical proof of such claim.

V. Conclusion

The digital AM receiver in Figure 1 has been implemented and its performance was found better than the noise figures presented here would predict. Several improved configurations of the digital AM receiver are being studied. Their performance will be evaluated. We will also address problems, such as front-end noise rejection, usage of recursive digital filter, alternative peak detection scheme to improve quantization noise and cost performance measures, associated with the design and implementation of the digital AM receiver.

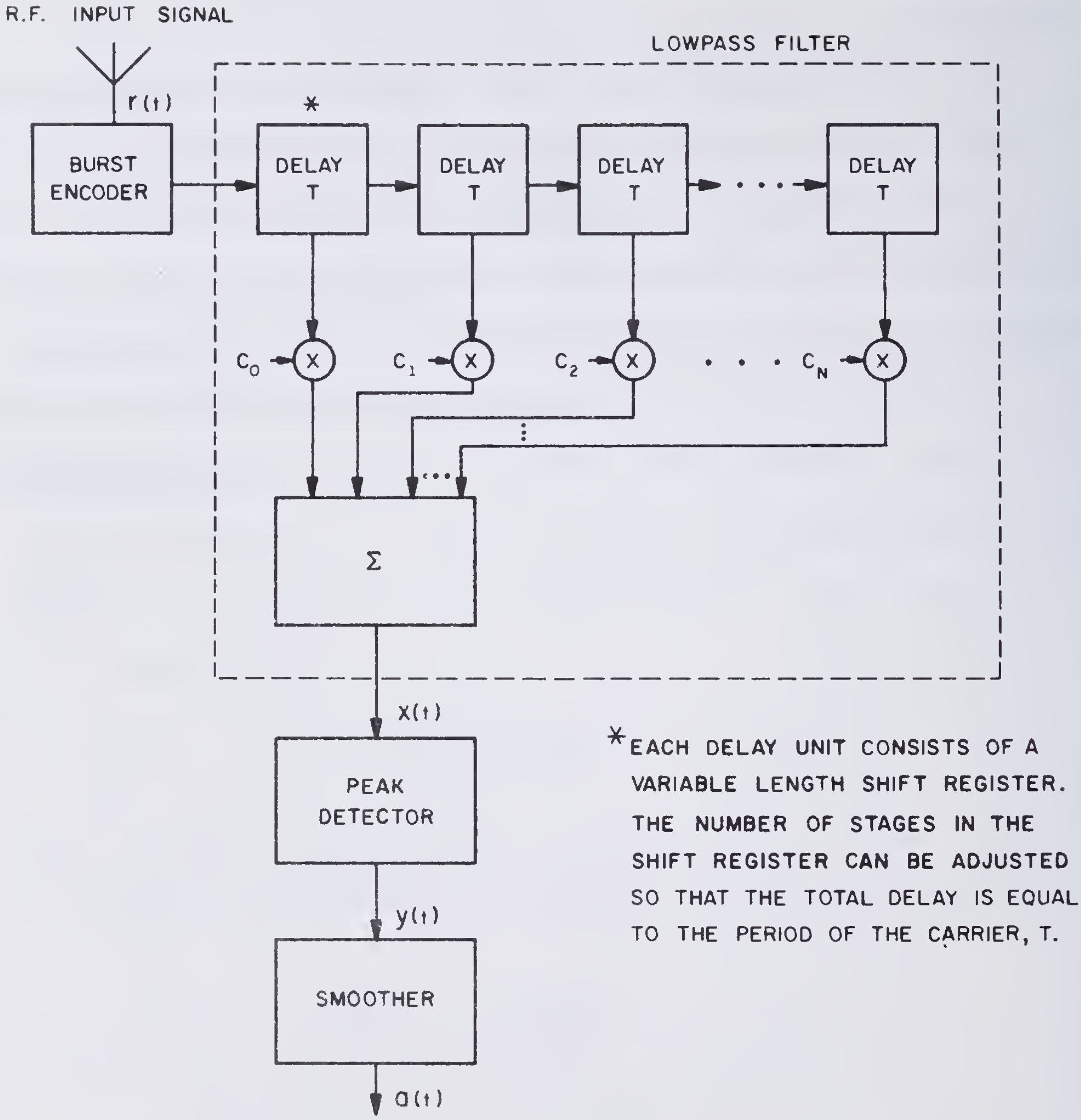


Figure 1. Block Diagram of Digital AM Receiver

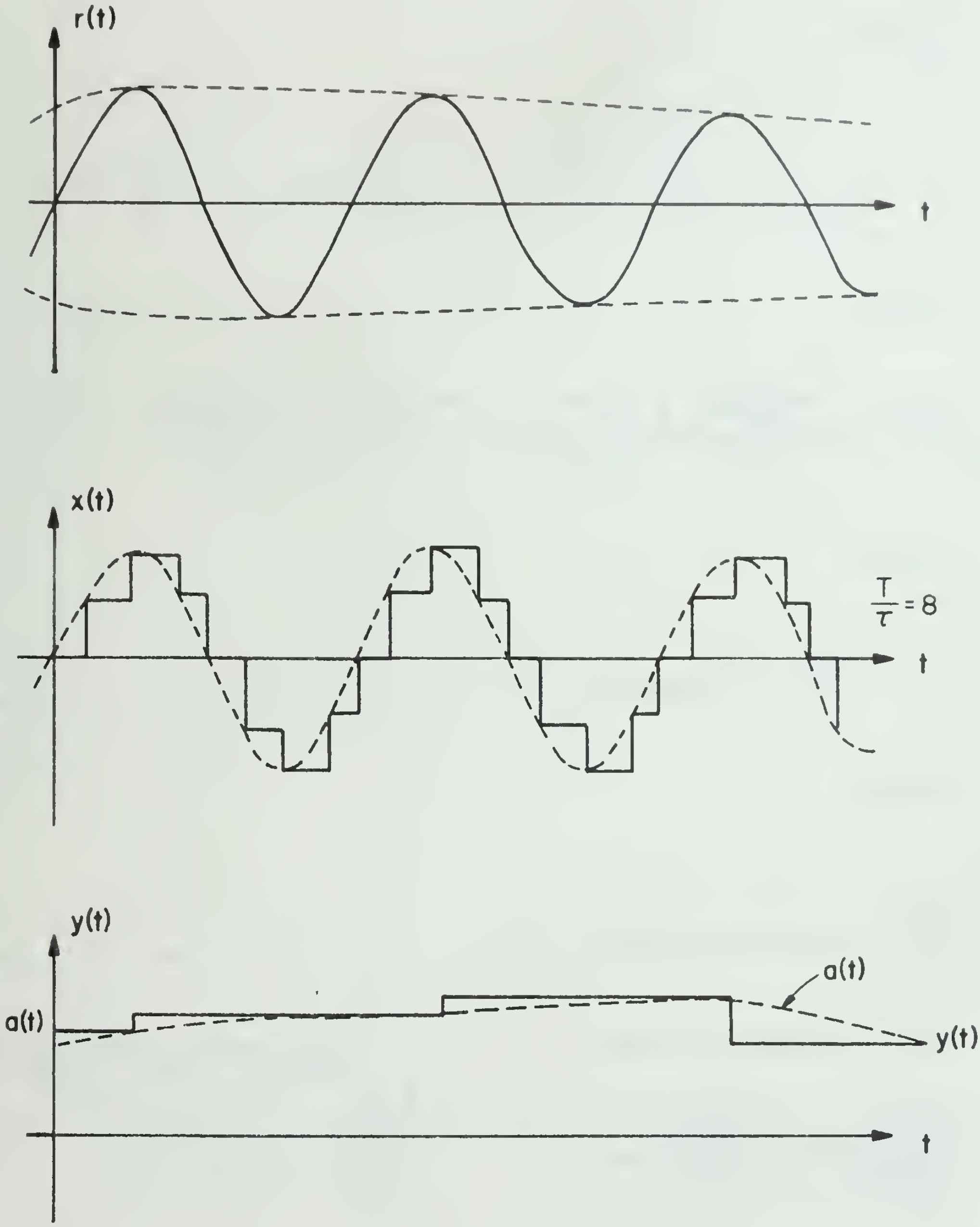


Figure 2. Typical Waveforms

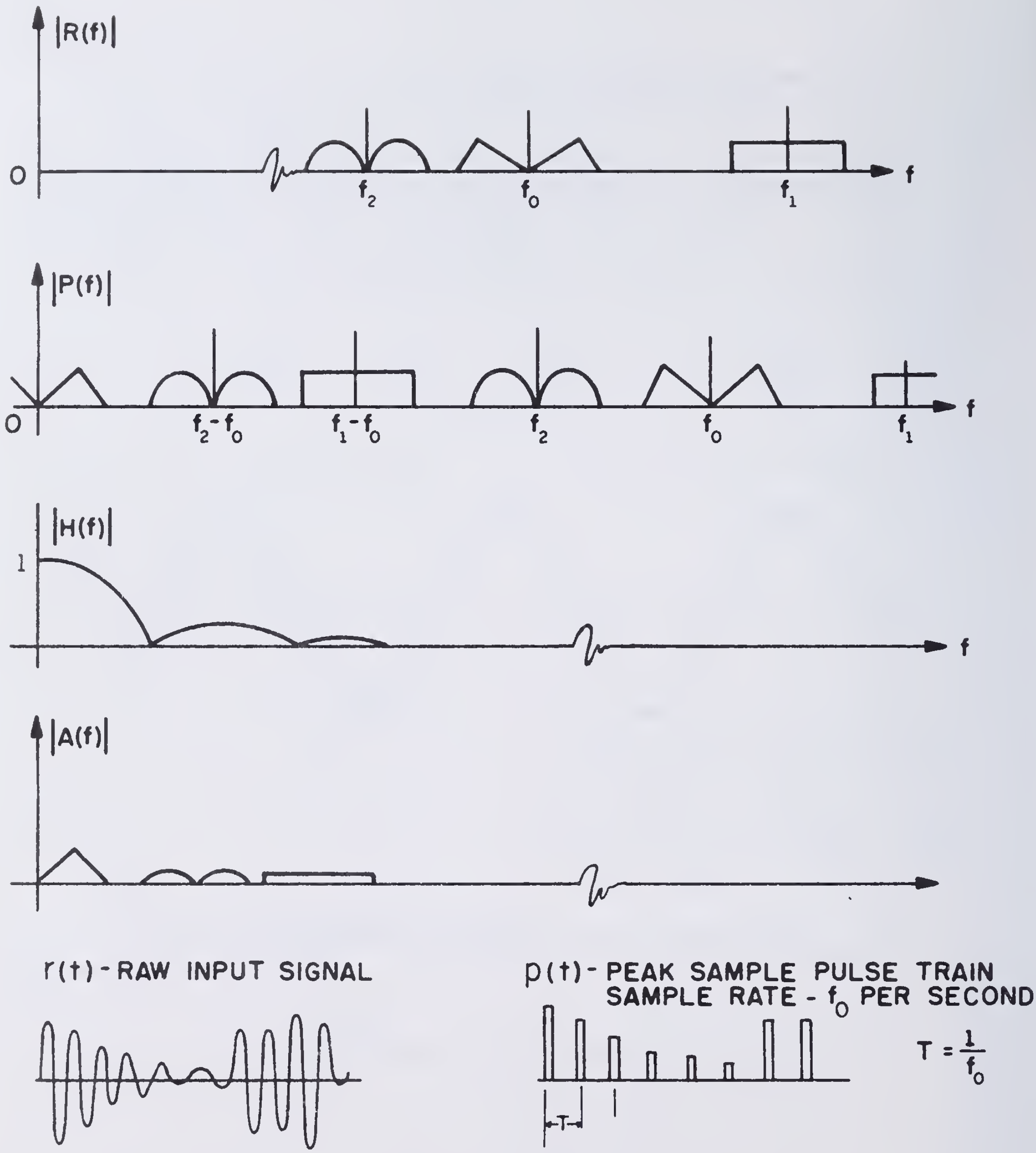


Figure 3. Typical Frequency Spectra of Signals

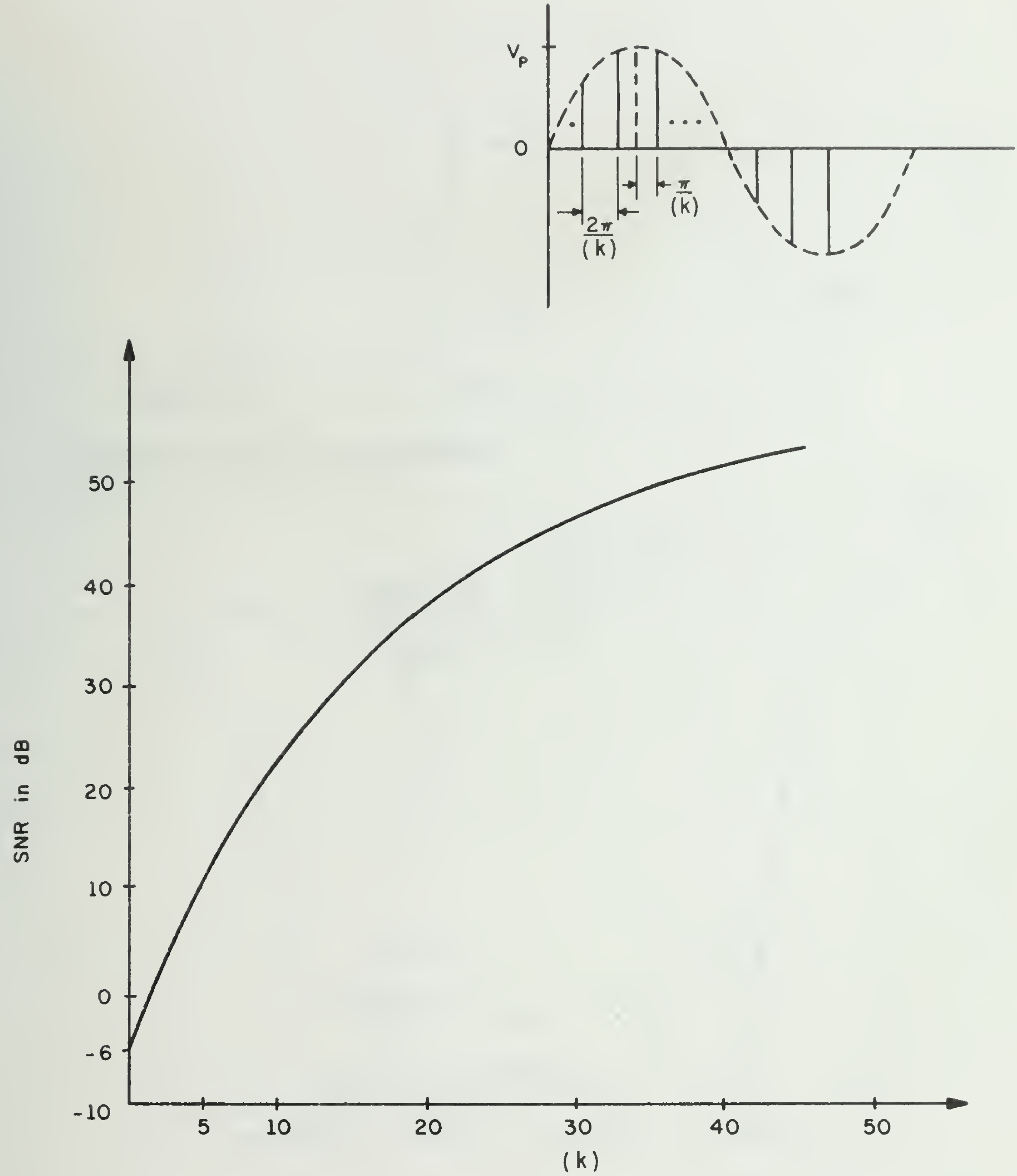


Figure 4. Peak Dectector Noise as a Function of Sampling Time Error $(\frac{\pi}{K})$.

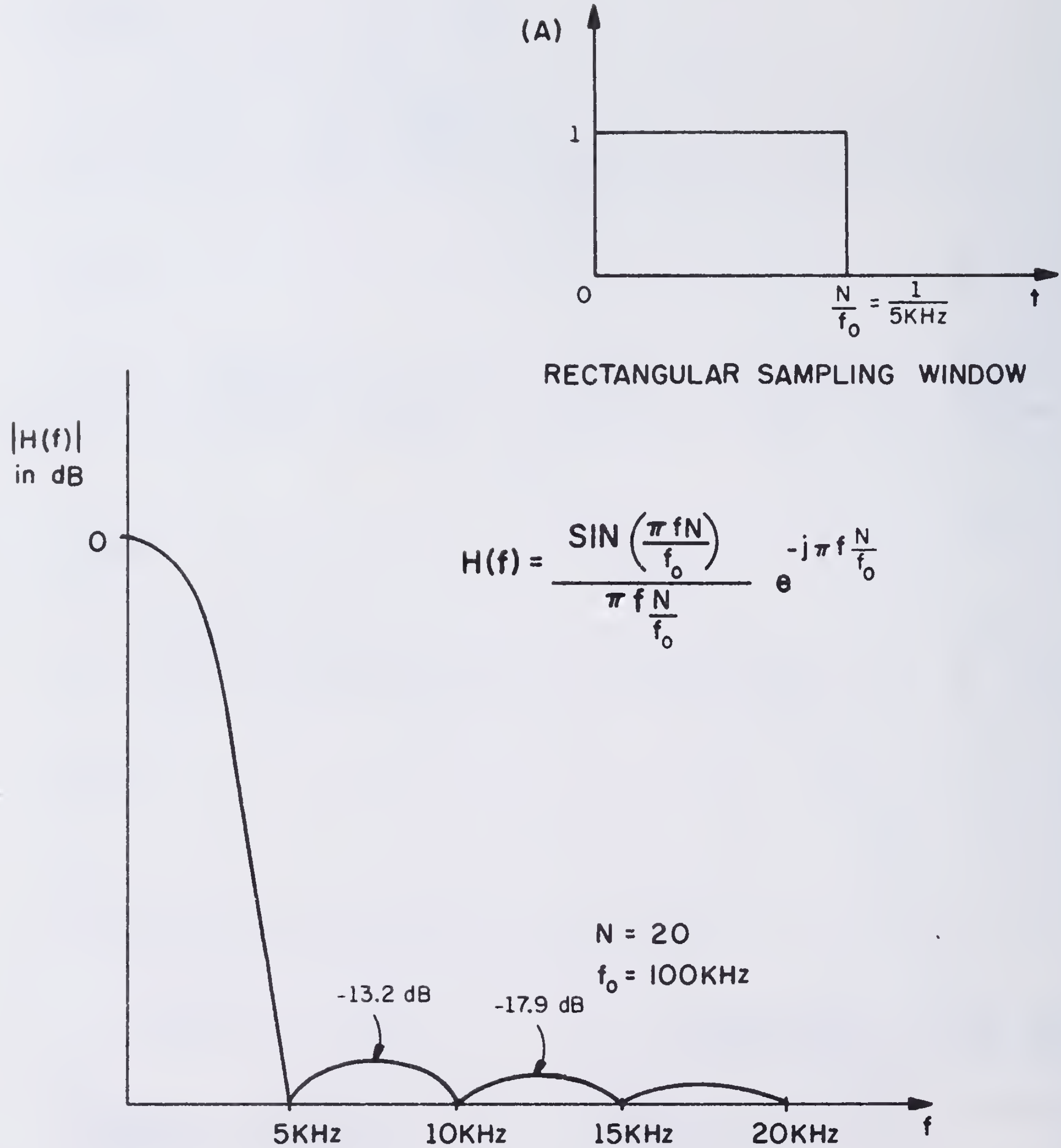
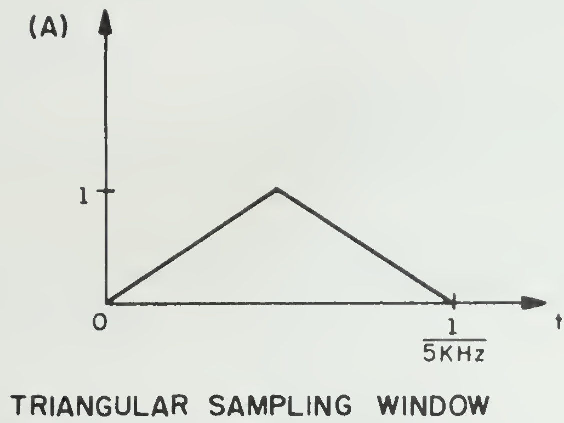


Figure 5. Frequency Response of the Lowpass Filter Implemented todate.



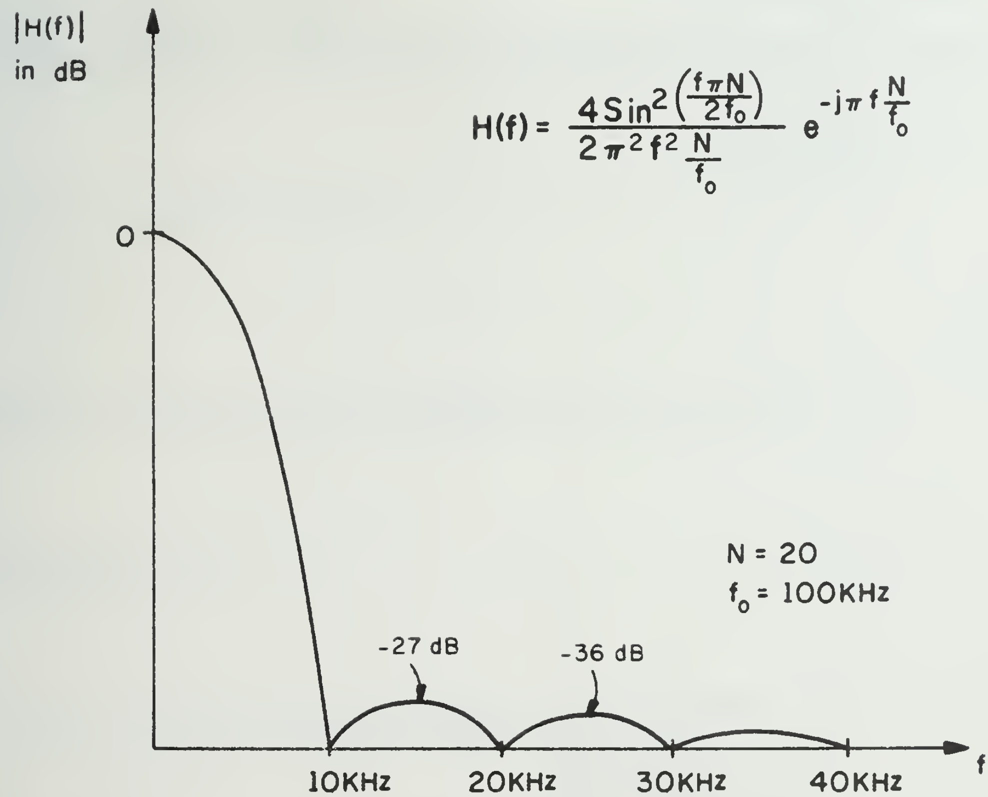


Figure 6. Frequency Response with Triangular Window

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